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Neutral Beam Injection for Plasma and Magnetic Field Diagnostics[1]**

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At the Lawrence Berkeley National Laboratory (LBNL) a diagnostic neutral beam injection system for measuring plasma parameters, flow velocity, and local magnetic field is being developed. The systems is designed to have a 90 % proton fraction and small divergence with beam current at 5-6 A and a pulse length of ~1 s occurring once every 1-2 min. The ion source needs to generate uniform plasma over a large (8 cm x 5 cm) extraction area. For this application, we have compared RF driven multicusp ion sources running with either an external or an internal antenna in similar ion source geometry. The ion beam will be made of an array of 6 sheet-shaped beamlets. The design is optimized using computer simulation programs.

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I. INTRODUCTION

At the Lawrence Berkeley National Laboratory (LBNL) a diagnostic neutral beam injection system is being developed in collaboration with Nova Photonics Inc. The neutral beam can be used to measure the ion temperature[i ii] and flow velocity[iii], plasma fluctuations[iv] and local magnetic fields inside the plasma[v]. High proton fraction and small divergence is essential for diagnostic neutral beams. In our design, a neutral hydrogen beam with an 8 cm x 11 cm (or smaller) elliptical beam spot at 2.5 m from the end of the extraction column is produced. This corresponds to full angular divergence of < 60 mrad in y direction and < 10 mrad in x direction. The beam will deliver 5-6 A of ion beam to the target with a pulse width of ~1 s, once every 1 – 2 min. The H_1^+ ion fraction of the hydrogen beam will be over 90 %. The ion source needs to generate uniform plasma over a large (8 cm x 5 cm) extraction area.

The ion beam will be extracted and accelerated by a set of grids with slits, thus forming an array of 6 sheet-shaped beamlets. The multiple grid extraction will be optimized using computer simulation programs. Neutralization of the beam will be done in a neutralization chamber, which is expected to have ~ 70% neutralization efficiency. A schematic diagram of the neutral beam injection system is shown in Fig. 1 In this article we concentrate on the ion source and the extraction design.

For this application, we have compared two types of RF driven multicusp ion sources operating at 13.56 MHz. The first one is an ion source with an external spiral antenna behind a dielectric RF-window. The second one uses an internal antenna in similar ion source geometry.

II. ION SOURCE

With a 8 cm x 5 cm extraction area, the required current density is 150-250 mA/cm^2. According to ion trajectory simulations, the plasma uniformity over the extraction area needs to be within 10%. We have tested ion sources with either internal or external RF-antenna as shown in Fig. 2. The RF-power is impedance matched to the ion source by using a step down matching network[vi].

The ion source is built with an aluminum body and has multicusp magnetic field to confine the plasma and improve plasma uniformity. The external antenna is spiral shaped and is made of water-cooled copper tubing. The back flange/RF-window is a movable quartz disk that allows adjustment of the source length. The internal antenna, which has two turns, is constructed by inserting a wire inside a water-cooled quartz tube. In this case the back flange is an aluminum disk with multicusp magnets.

Figures 3-5 present the data taken from both source geometries. The sources operated effectively under 8 mTorr pressure. Low operation pressure is important because it reduces charge exchange and voltage breakdown problem in the extraction region. The impurities was found to be high during a recent test resulting in an effective ion mass of ~6 amu. Nevertheless previous experiments[vii, viii, ix] at LBNL with similar sources have found that the effective mass was ~1.2 amu. We suspected that the problem was due to impurities from the aluminum wall and are planning to change the wall material to alumina.

In the external antenna case, the aspect ratio of (source depth)/(source diameter) was ¼. For internal antenna the ratio was ½. Small aspect ratio enables the external antenna to generate high plasma densities with non-ideal the plasma uniformity. Fig. 5 presents the measured plasma density profiles from both sources. The source with internal antenna is capable of producing the required plasma uniformity (<10%). However, we believe that by changing the aspect ratio in the external antenna source will improve the plasma uniformity and therefore meets the requirements.

III. EXTRACTION

Ion source extraction is designed by using particle trajectory simulation code IBsimu[x] that can handle multiple beamlets (including the electrostatic interaction between beamlets). For single slit problem the newly developed IBsimu was benchmarked against the more established BPGUNS[xi]. The beam has strict divergence (rad) and beam spot size (cm) requirements in the x direction.

We have considered both multiple slit and multiple hole extraction. The multiple slit extraction (see Fig 6) was selected due to the very small divergence in the long direction (x) of the slit and high transparency of the slit design. The beam is extracted from six ~8 cm long slits using simple triode extraction. The length of the extraction section needs to be minimized in order to maximize vacuum pumping and minimize the heating of the electrodes caused by charge exchange in the region. The specially shaped plasma electrode produces focusing fields that are very linear and thus the aberrations in the beam emittance are smaller. The plasma electrode will be actively water-cooled. The two other electrodes are "edge-cooled" and are designed to allow free expansion at one end in order to avoid warping.

Due to the large extraction area, the pressure in the extraction gap is significant. This design keeps the voltage gradients at ~50 kV/cm to prevent sparking problems. For such long drift distance (~2.5 m) the overall machining/alignment tolerances need to be less than 20 micron in the y direction. Fig. 7 shows the profiles of the beam in y and y' coordinates at the target 2.5 m downstream from the last electrode.

CONCLUSIONS

The experimental data has suggested using an internal antenna for the ion source because of its capability to operate at lower pressure and produce very uniform plasma density. External antenna also has the potential problem of back streaming electrons damaging the rear dielectric window (unless protected by shielding).

Based on computer simulation, this three-grid extraction system can deliver the neutral H_1^0 particle flux of $1.9 \cdot 10^9$ - $2.3 \cdot 10^9$ particles/s (assuming 90% H_1^+ fraction and 70% neutralization) to the target with a full angular divergence of ~ 40 - 50 mrad and a beam size ~10 cm in the y direction.

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Figures and figure captions

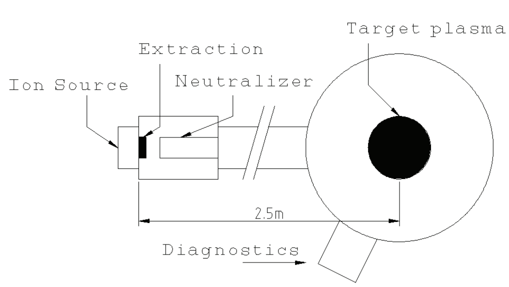

Figure 1: Neutral beam injection system block diagram.

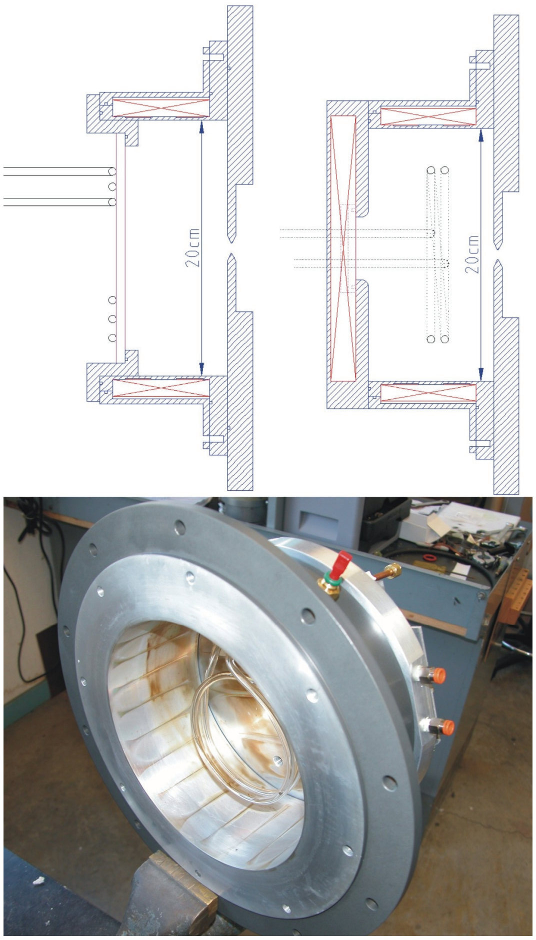

Figure 2: Schematics of the test sources with internal and external antenna and the picture of the source with internal antenna. The source is made of aluminum (blue) and has multicusp confinement magnets (red).

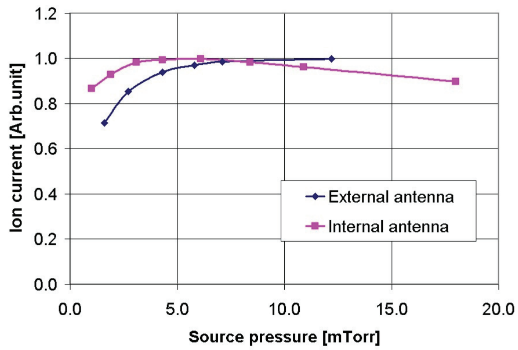

Figure 3: Extracted ion current vs. operating pressure.

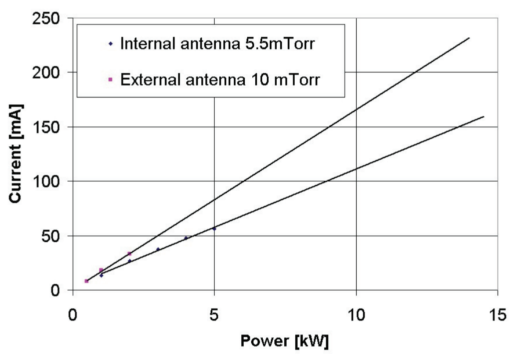

Figure 4: Extracted ion current vs. RF-power.

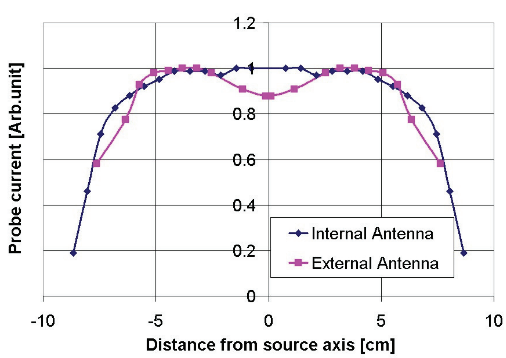

Figure 5: Plasma density profiles obtained from a movable Langmuir probe.

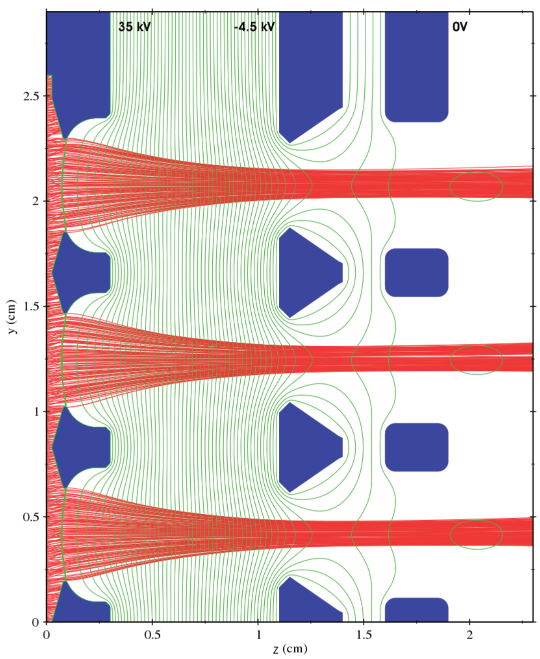

Figure 6: Ion trajectory plot from IBsimu for multiple slit extraction.

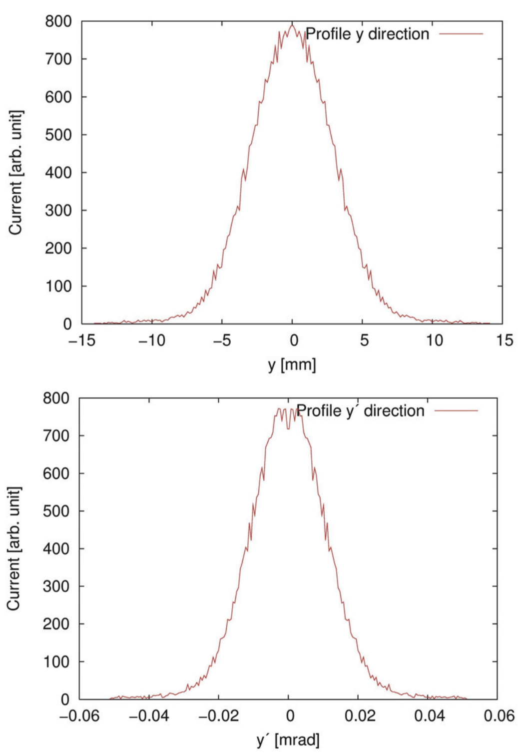

Figure 7. Beam profile in y and y' at the target, at 2.5m downstream from the last extraction electrode.

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